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Moist-Soil Impoundments for Wetland Wildlife

by John J. Lane, Tennessee Technological University
Kent C. Jensen, ERDC

Prepared for Headquarters, U.S. Army Corps of Engineers

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by John J. Lane

Tennessee Technological University
Cookeville, TN 38501

Kent C. Jensen

U.S. Army Engineer Research and Development Center
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Moist-Soil Management Report Summary

Moist-Soil Impoundments for Wetland Wildlife (TR EL-99-11)

ISSUE: As wetland acreage continues to decline, judicious management of remaining habitat to meet the biological needs of wetland wildlife has become increasingly important. Managed moist-soil habitats are shallow-water areas impounded by levees, which contain water-control structures that enable flooding during fall and winter and dewatering during spring and summer. Flooding provides foraging habitat and cover for diverse communities of migrating and wintering waterfowl and other waterbirds. Drawdowns promote germination and growth of plants adapted to moist or shallowly flooded sites. The goal of moist-soil management is to maximize the production of naturally occurring wetland vegetation to optimize use of wetland habitats by wildlife.

RESEARCH OBJECTIVE: This report was prepared as a guide to assist Corps biologists and natural resource managers in developing moist-soil impoundments that will benefit wildlife using wetland habitats. Emphasis is placed on developing a moist-soil management program that provides benefits to a variety of species. A well-designed moist-soil management program should contribute to increasing and maintaining the biodiversity of an area.

SUMMARY: The use of moist-soil impoundments is especially effective for managing waterfowl habitat in areas of declining wetland acreage. This technique promotes production of naturally occurring wetland vegetation by emulating natural wetland functions. This report describes the design and construction of moist-soil impoundments, including desirable site characteristics, levee construction and placement, water-delivery systems, and control structures. The stewardship value of moist-soil impoundments is discussed, and recommendations are given for managing impoundments as single structures or as complexes of smaller units. Strategies are presented for controlling undesirable vegetation and for managing impoundments to accommodate a diversity of wildlife species. The application of moist-soil impoundments to an ecosystem management approach on Corps projects is emphasized.

AVAILABILITY: This report is available on Interlibrary Loan Service from the U.S. Army Engineer Research and Development Center (ERDC) Library, Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2355.

About the Authors: The report was written by Mr. John J. Lane, Tennessee Technological University, Cookeville, TN, and Dr. Kent C. Jensen, ERDC. Mr. Lane is currently with the Arkansas Game and Fish Commission, Little Rock, AR, and Dr. Jensen is now an Associate Professor at Oglala Lakota College, Kyle, SD. Point of Contact is Mr. Chester O. Martin, ERDC, telephone (601) 634-3958.

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Preface

This work was sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Ecosystem Management and Restoration Research Program (EMRRP), under a work unit entitled "Improved Methods for Ecosystem-Based Habitat Management at Corps Projects." Mr. Chester O. Martin was Principal Investigator for the work unit. Mr. Dave Mathis, CERD-C, was the EMRRP Coordinator at the Directorate of Research and Development, HQUSACE. The Program Monitors for the study were Mr. Pete Juhle, Ms. Cheryl Smith, Ms. Denise White, and Ms. Colleen Charles, HQUSACE.

This report was prepared by Mr. John J. Lane, Tennessee Technological University, Cookeville, TN, and Dr. Kent C. Jensen, Stewardship Branch (SB), Natural Resources Division (NRD), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC). Mr. Lane was employed by ERDC under a Student Contract Agreement with Tennessee Technological University during the development of this report; he is currently a biologist with the Arkansas Game and Fish Commission (AGFC), Little Rock, AR. Dr. Jensen is now Associate Professor and Director of Undergraduate Research at Oglala Lakota College, Kyle, SD. Report review was provided by Ms. Julie Marcy, USACE, Vicksburg, MS, and Mr. Robert S. Holbrook, AGFC, Little Rock, AR. ERDC review was provided by Mr. Martin, Mr. Darrell E. Evans, and Dr. Wilma A. Mitchell, SB.

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1 Introduction

As wetland acreage continues to decline in the conterminous United States (Dahl 1990), intensive management of remaining habitat to meet the biological needs of wetland wildlife (especially waterfowl) has become increasingly important (Reid et al. 1989). Changes in policy emphasis, such as management of nongame wildlife species, natural habitats, and biodiversity also confront wildlife managers (Faaborg 1986; Fredrickson and Reid 1986; Sweeny and Henderson 1986). Budgetary constraints continue to increase, thus demanding that managers gain the greatest benefit for the least expenditure (Mangun 1986). The technique of moist-soil management provides a mechanism for managers to meet these challenges.

The term and concept of "moist-soil" plant production, introduced by Frank Bellrose in the 1940s, referred to plant species that grew on exposed mud flats after surface water retreated in spring or summer (Fredrickson and Taylor 1982). Bellrose had observed that waterfowl often concentrated on these sites and consumed natural foods. From 1968 to 1982, the concepts and techniques of moist-soil management were developed at Mingo National Wildlife Refuge in southeastern Missouri and published by Fredrickson and Taylor (1982). The information in this report has been drawn predominantly from their work with the integration of additional findings since 1982.

Managed moist-soil habitats are shallow-water areas impounded by levees, which contain water-control structures that enable flooding during fall and winter and dewatering during spring and summer. Flooding provides foraging habitat and cover for diverse communities of migrating and wintering waterfowl and other waterbirds (Fredrickson and Taylor 1982; Reid 1989; Reid et al. 1989; Reinecke et al. 1989). Drawdowns (dewatering to mud flat conditions) promote germination and growth of plants adapted to moist or shallowly flooded sites (Low and Bellrose 1944; Fredrickson and Taylor 1982). These plants produce rich food sources of aquatic invertebrates, seeds, tubers, and browse for waterfowl, shorebirds, other waterbirds, and some upland wildlife (Reid 1983; Reinecke et al. 1989; Krapu and Reinecke 1992). Although moist-soil management is most often applied to man-made impoundments (Fredrickson and Taylor 1982), natural wetlands with modified hydrology or degraded habitats can be enhanced, and value for wildlife can be increased by utilizing moist-soil management techniques (Reid et al. 1989). Sites too wet for consistent production of row crops or establishment of upland vegetation, yet too dry for the management of aquatic plants, are especially well suited for development of moist-soil impoundments (Fredrickson and Taylor 1982).

The purpose of moist-soil management has been to increase wetland productivity and waterfowl use on migrating and wintering grounds (McEwan 1979; Fredrickson and Taylor 1982; Bolen et al. 1989; Kadlec and Smith 1989). The current goal of wildlife managers utilizing moist-soil techniques is to maximize production of naturally occurring wetland vegetation in order to optimize use of wetland habitats by wildlife. Moist-soil management promotes the production of naturally occurring wetland vegetation by emulating and manipulating natural wetland functions (e.g., hydrology and successional stage). Wetland hydrology is usually controlled by constructed water delivery, control, and discharge systems. The successional stage of an area is manipulated by soil or vegetative disturbances or prolonged inundation. Vegetative composition and density of a moist-soil site are influenced by altering the timing and duration of drawdowns and stage of succession. To maximize habitat availability and utilization, depth and timing of flooding are manipulated according to the habitat requirements and migration or breeding phenology of wildlife species (Fredrickson and Taylor 1982). Through precise control of hydrology and manipulation of plant succession, wildlife managers can achieve desired plant communities and provide habitat requirements for a variety of wildlife species throughout their annual cycles.

2 Stewardship Value

Moist-soil management techniques provide a mechanism for enhancement of established wetlands, restoration of former wetlands, and creation of new wetland habitat. Enhancement of wetlands occurs in areas where hydrology and habitat have been degraded and active management is required to renew wetland functions and improve value as wildlife habitat. Areas where wetlands previously existed are often unproductive for alternative land uses because of altered hydrology but are well suited for restoration. Creating wetlands where none previously existed helps offset wetland habitat losses (Weller 1990).

Waterfowl

Agricultural row crops are important sources of high-energy foods for large concentrations of migrating and wintering waterfowl, mainly geese and mallards[1] (Gilmer et al. 1982; Reid et al. 1989; Reinecke et al. 1989; Ringelman 1990), but fail to provide adequately for many other waterfowl and wildlife species (Fredrickson and Taylor 1982; Heitmeyer 1985; Reid et al. 1989). The value of wetland plants for waterfowl foods is well documented (Martin and Uhler 1951; Wright 1959; Wills 1971; Heitmeyer 1985; Delnicki and Reinecke 1986; Combs 1987; Fredrickson and Reid 1988a). Many wetland plants have higher overall nutritive qualities, contain more essential amino acids, and provide more cover than cereal grains (Burgess 1969; Fredrickson and Taylor 1982; Fredrickson and Reid 1988a; Heitmeyer and Fredrickson 1990; Laubhan 1992). Moist-soil impoundments also contain a variety of aquatic invertebrate species (Wiggins et al. 1980; Reid 1983) that are critical to waterfowl diets during periods of the annual cycle (Chura 1961; Swanson and Meyer 1973, 1977; Krapu 1974, 1979; Drobney and Fredrickson 1979; Eldridge 1990). Consequently, a more diverse waterfowl population is attracted to moist-soil impoundments than to flooded agricultural row crops (Taylor 1977).

1 Common and scientific names of animal species are given in Appendix A.

Biodiversity

Moist-soil management contributes to increasing and maintaining the biodiversity of an area. Moist-soil impoundments more closely resemble natural habitats and provide required habitat parameters for a larger variety of game and nongame wildlife species than monotypic agricultural row crops (Taylor 1977; Rundle and Fredrickson 1981; Fredrickson and Taylor 1982; Fredrickson and Reid 1986). Over 80 percent more species have been found to occur in moist-soil impoundments than in adjacent row crops and include invertebrates, herpetofauna (amphibians and reptiles), prairie and marsh passerines (small- to medium-sized perching birds), shorebirds, wading birds, waterfowl, gallinaceous birds (e.g., pheasants, wild turkeys), raptors, and mammals (Table 1) (Fredrickson and Taylor 1982). Fredrickson and Reid (1986) observed >150 avian species on moist-soil impoundments on the Ted Shanks Wildlife Area and Mingo National Wildlife Refuge, Missouri. Areas managed for upland wildlife attract ring-necked pheasants, wild turkeys, and northern bobwhites, which use the sites for brooding and feeding. White-tailed deer forage in moist-soil habitats and use areas of abundant, dense vegetation as nurseries when impoundments are dry. Rabbits and other small mammals find food, cover, and nesting sites during dry periods, and passerine birds are attracted to the new vegetative growth (Fredrickson and Taylor 1982). Furbearers such as raccoons, minks, and muskrats benefit from wetland conditions provided by moist-soil impoundments.

Effectiveness

Moist-soil management is a more cost-effective technique than row-cropping for providing food and cover for a variety of wildlife species (Fredrickson and Taylor 1982). Productive row-cropping requires annual seeding and periodic applications of fertilizer, herbicides, and pesticides. Moist-soil management has been productive without these applications (Fredrickson and Taylor 1982); however, seed bank establishment may be required at highly degraded sites (van der Valk and Pederson 1989), and herbicide application may be required in extreme cases. Return of energy (kilocalorie of food in the form of seeds) for each unit of energy input (kilocalorie of fuel, chemicals) for moist-soil plant production is regularly 7.17 kilocalories (Fredrickson and Taylor 1982). This does not include root, tuber, browse, herpetofauna, or invertebrate production, which would increase this figure. The national average energy return for corn is 2.82 kilocalories. Many wetland plant seeds also resist deterioration longer when flooded than do cereal grains (Neely 1956; Shearer et al. 1969). Neely (1956) showed that after 90 days of continuous inundation, soybeans[1] and corn deteriorated 86 and 50 percent, respectively, while

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1 Common and scientific names of plant species are given in Appendix B.

Table 1
Birds and Mammals That Have Responded to Moist-Soil Management in the Midwest[1]

Pied-billed grebe	Golden eagle	Barred owl
American bittern	Northern harrier	Short-eared owl
Least bittern	Red-shouldered hawk	Common nighthawk
Great blue heron	Red-tailed hawk	Chimney swift
Great egret	Wild turkey	Belted kingfisher
Snowy egret	Northern bobwhite	Eastern kingbird
Little blue heron	Ring-necked pheasant	Tree swallow
Cattle egret	King rail	Bank swallow
Green-backed heron	Virginia rail	Barn swallow
Black-crowned night heron	Sora	American crow
Yellow-crowned night heron	Common moorhen	Sedge wren
Tundra swan	American coot	Marsh wren
Snow goose	Killdeer	Common yellowthroat
Canada goose	Greater yellowlegs	Indigo bunting
Wood duck	Lesser yellowlegs	Dickcissel
Green-winged teal	Solitary sandpiper	Song sparrow
Blue-winged teal	Willet	Swamp sparrow
American black duck	Spotted sandpiper	White-throated sparrow
Mallard	Least sandpiper	White-crowned sparrow
Northern pintail	Pectoral sandpiper	Red-winged blackbird
Northern shoveler	Dunlin	American goldfinch
Gadwall	Common snipe	Muskrat
American wigeon	American woodcock	Raccoon
Ring-necked duck	Mourning dove	Mink
Hooded merganser	Barn owl	White-tailed deer
Bald eagle	Great horned owl	Rabbits

[1] Sources: Fredrickson and Taylor (1982), Fredrickson and Reid (1986).

saltmarsh bulrush and smartweed deteriorated 1 and 21 percent, respectively. Many wetland plant seeds may persist for several months or even years while flooded (Fredrickson and Taylor 1982). Adverse weather conditions may reduce row crop production but have less effect on natural vegetation because of the diversity of plant species adapted to wetland conditions (Figure 1).

Regional Application

Moist-soil management procedures have been most widely applied to waterfowl management in areas of migrational and wintering habitat. Although general ecological and management principles of moist-soil habitats have broad applications, specific techniques (e.g., timing of draw-downs and flooding) and their results vary with changes in latitude because of various aspects of wetland plant distribution and seed germination traits. To be successful, wetland managers must duplicate hydrologic conditions of their regions, monitor plant and animal responses, and adjust

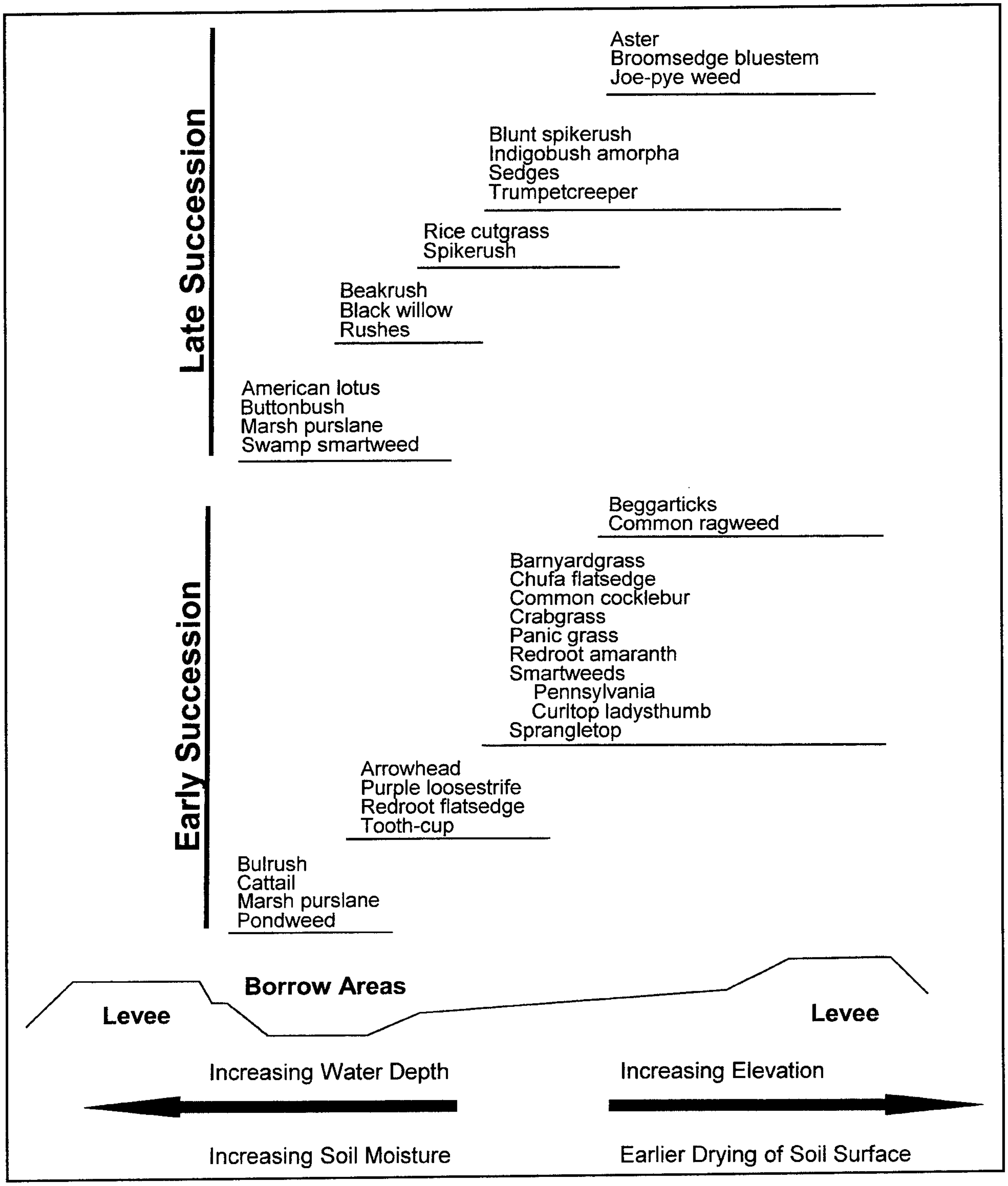

Figure 1. Distribution of common moist-soil plants along a flooding gradient (Fredrickson and Taylor 1982)

management to conditions at their specific locations (Fredrickson and Taylor 1982).

Although moist-soil management technology was initially developed and extensively tested in the upper Midwest and Mississippi Alluvial Valley, the practice has potential application in other areas. Moist-soil management is used to some extent throughout the Southeast to stimulate growth of waterfowl food plants (Johnson and Montalbano 1989; Gordon et al. 1989), but little experimental work has been published on the effectiveness of moist-soil management in the south-central United States where the growing season is long, the climate is warmer, and southern plant assemblages are involved (Polasek et al. 1995). Preliminary studies indicate that moist-soil management can potentially improve waterfowl habitat in portions of Georgia (Larimer 1982; Jensen and Reynolds 1997). Partial drawdowns, drawdown timing, and soil disturbance were effective tools in creating diverse habitats in shallow impoundments in northern Texas (Polasek et al. 1995).

Several National Wildlife Refuges in the Chesapeake Bay and North Carolina sounds region have recently been using moist-soil management along with other traditional practices to improve waterfowl habitat (Hindman and Stotts 1989). In North Carolina, moist-soil impoundments are drawn down in April to encourage annual plants, such as barnyard grasses, panicums, American bulrush, squarestem spikerush, smartweeds, redroot flatsedge, and beggarticks. Impoundments are reflooded in October-November to make food resources available to migratory waterfowl.

Various levels of moist-soil management have also been applied in the western States. Mushet et al. (1992) stated that wildlife managers in the Central Valley of California use various water-management techniques to maximize waterfowl use during winter and periods of migration. These managers follow the general pattern of flooding wet areas in late summer and early fall, keeping them flooded in winter, and draining them in spring to stimulate germination of moist-soil annuals. Swamp timothy is considered a target moist-soil species in many Central Valley wetlands; other important waterfowl food and cover plants in the Sacramento Valley are prickle grass, common barnyard grass, and sprangletop.

Moist-soil management is being used to promote germination, growth, and seed production of mud flat annuals for wintering waterfowl in playa (desert basin) wetlands (Haukos and Smith 1993, 1996). The effects of moist-soil management were evaluated on soils of eight playa wetlands in the Southern High Plains of Texas. Wetland flooding occurred primarily from overland runoff of precipitation and secondarily from runoff of irrigation operations. Moist-soil management reduced soil resistance for germination and raised pH closer to neutrality but had no effect on soil moisture in the top 4 cm of soil. Nitrogen and phosphorus levels in playa soils were not affected during the two seasons of study. Haukos and Smith (1996) stated that moist-soil management is a sustainable and compatible practice for playa wetlands because it enhances naturally occurring events.

3 Design and Construction

The development of moist-soil impoundments requires careful preliminary site considerations, detailed planning and design, and proper construction. Specialists such as wetland biologists, agronomists, hydrologists, and engineers should be consulted during each phase of development to ensure correct decision making. For successful management, moist-soil managers should acquire a thorough knowledge of the life history requirements of moist-soil flora and fauna and develop the ability to identify these species. Regular inspections of impoundments are required to monitor plant responses and wildlife use relative to management manipulations. Field notes to document these responses are necessary to repeat or alter techniques that achieve desired management goals (Fredrickson and Taylor 1982).

Site Considerations

An inventory should be conducted to evaluate potential sites for the development of impoundments. Important considerations include location in the flyway or area of waterfowl concentration, water source, soil type, topography, impoundment size, number of units, levee construction, and construction of a water delivery, control, and drainage system. Payne (1992) provides detailed information on site selection inventories, conditions qualifying potential sites for impoundment construction, and potential for waterfowl management. Specific management goals and biological aspects of target species must also be considered. Professional advice should be sought to ensure proper planning, design, and implementation (Fredrickson and Taylor 1982; Reid et al. 1989; Erwin 1990; Payne 1992; Kelley et al. 1993). The Wetlands Engineering Manual (Massey, undated) provides excellent guidelines for the design and construction of the physical structures associated with moist-soil impoundments.

Water source

Water-source dependability, quantity, and quality are important aspects affecting successful management and require prudent consideration. Available sources of water for flooding are rainfall, groundwater, rivers/streams, and reservoirs. Rainfall is the least costly source but also the least dependable because of the unpredictability of timing and quantity of rain events (Reid et al. 1989). Fredrickson and Taylor (1982) reported successful management on some southern sites where annual rainfall is ≥100 cm (39.3 in.). Groundwater is usually very dependable and plentiful but may be deficient in some nutrients necessary for plant growth. A groundwater source requires the drilling of a well and installation of a pumping system, both of which increase costs. River/stream sources are more dependable than rainfall but are subject to watershed rainfall patterns; therefore, variation in annual streamflow is a major consideration. Reservoirs can provide a dependable source of floodwater, but availability is subject to proximity, impoundment size, and compatibility with current use. Reservoir construction may be an alternative, but additional costs and impacts to surrounding habitat must be considered. Prior to impoundment use, surface and groundwater should be analyzed to determine water quality and prevent potential poisoning of wildlife (Reid et al. 1989).

Soils

Determination of soil type and texture is required to ensure sound construction and efficient management of impoundments. Natural Resources Conservation Service offices can provide soil survey maps and technical assistance (Fredrickson and Taylor 1982; Payne 1992). For site selection purposes, soils can be divided into two general types, organic and mineral. Organic soils in wetlands tend to have fewer total nutrients with more minerals in organic forms that are unavailable to plants. Mineral soils have less than 20 to 35 percent (dry weight) organic material and are therefore preferred for plant production. Organic soils <30 cm (10 in.) thick, underlaid with mineral soils, are appropriate for vegetative production. Soils with silt, clay, loam, or very fine sand content will hold water and are well suited for impoundment construction, whereas soils composed of coarse sand or gravel are too porous to retain water and therefore poorly suited for impoundments (Payne 1992). These soil textures can erode or allow water seepage that may result in levee deterioration, high turbidity levels, and increased costs for maintaining water levels that can be prohibitive to management (Fredrickson and Taylor 1982).

Topography

Topography influences impoundment basin morphometry, levee placement, and water control. The impoundment basin should have a gradient of <1 percent, or <1-m (3.3-ft) elevation in 100 m (330 ft), which will allow the majority of the area to be flooded to depths of 5 to 30 cm (2 to 12 in.)

(Fredrickson and Taylor 1982; Payne 1992). Slight variations in topography cause small undulations in basin morphometry and are advantageous because microhabitats important to a number of plant and animal species are created (Reid et al. 1989). Polasek (1994) reported that an impoundment with extensive shallow-sloped areas and a deeper pool increased both plant and waterfowl diversity. In areas with slight slopes, contour levees can be used to facilitate uniform flooding depths; however, steep slopes require many contour levees within a small area. This may decrease impoundment size and increase construction costs to levels that are prohibitive to and inconsistent with management goals. Additional water-control structures may also be necessary and further increase costs (Fredrickson and Taylor 1982; Kelley et al. 1993).

Management Units

The size and number of moist-soil units should be determined by site characteristics, management goals, and available funds. The total impoundment area may vary from 1 to 1,500 ha (2.5 to 3,700 acres) (Reid et al. 1989), but 400 ha (1,000 acres) should be the maximum individual impoundment size (Beule 1979). Fredrickson (1991) stated that optimum impoundment size is 2 to 40 ha (5 to 100 acres); however, impoundments <4 ha (10 acres) can be too costly to develop (Hoffman 1988). Although more susceptible to disturbance than larger units, smaller units are easier to manage because precise water levels can be maintained. Larger units are less susceptible to disturbance and generally have greater biotic diversity but are more difficult to manage.

Several moist-soil units capable of independent operation should be available on a management area. Each unit can receive separate management treatments for different types of wildlife. Fredrickson (1991) suggested a minimum of five units within a 10-mile (16-km) radius of units. A moist-soil impoundment containing five units can be managed as a complex for waterfowl use (Fredrickson and Taylor 1982). As the number of units increases, more management options become available, and biological requirements can be provided for a greater diversity of wildlife species (Fredrickson and Reid 1986). A master plan can be developed that, by rotating management options among units, will continuously provide for maximum diversity of wildlife species (Fredrickson and Taylor 1982).

Location of moist-soil units is an important factor affecting waterfowl use. Juxtaposition of managed wetlands relative to other wetlands is important in attracting waterfowl to an area (Gordon et al. 1989). Small, well-managed wetlands adjacent to large wintering areas are more likely to attract waterfowl than are small, well-managed wetlands a long distance from large wintering areas. Disturbance should be considered when locating moist-soil units. Human activity, such as excessive hunting and heavy boat traffic, will cause disturbance that displaces waterfowl. Hunting pressure can impact waterfowl use, especially if units are small. In South

Carolina, Gordon et al. (1989) found that waterfowl will use managed wetlands <40 ha (100 acres) diurnally before and after hunting season, but only nocturnally during hunting season. This behavior is attributed to high hunter density in the area. If hunter density within a unit is limited, waterfowl will use managed wetlands >100 ha (250 acres) diurnally.

Levee Construction

Proper levee construction and placement allow for precise water control and are critical to successful management. Clay soils or silty clay loams are best suited for levee construction. These soil textures are highly compactible and have a low shrink-swell potential, thus ensuring long-term integrity (Kelley et al. 1993). If onsite soil is used, borrow areas can be located either inside or outside the levees. Inside borrow areas can provide deep, permanent water, promoting establishment of submergent vegetation (Fredrickson and Taylor 1982). Taylor (1977) reported that ring-necked ducks occurred exclusively on borrow areas in moist-soil impoundments. An elevated access must be established across borrow areas to facilitate transport of equipment into management units (Fredrickson and Taylor 1982). Placing borrow areas outside of levees can substantially reduce initial pumping costs when impoundment units are flooded (Reid et al. 1989). Payne (1992) extensively addressed procedures for levee construction.

Size of levees

Levees should be large enough to support heavy equipment (e.g., tractor, mower, disk) and resist rodent, wave, and ice damage. Exterior levees should be at least 3 m (10 ft) across the top with a side slope of 3:1 to 5:1 (Figure 2). Levee height and width are dependent upon impoundment size and expected depth of flooding. In locations where flood events are infrequent, levee height should be at least 0.6 to 1.0 m (2 to 3 ft) above maximum planned flooding depth. Flooding depths of 10 to 46 cm (4 to 18 in.) are recommended, thereby requiring a levee height of at least 1.0 m (3.3 ft). Areas where minor flood events occur regularly may require larger exterior levees to prevent inundation of impoundments. Where major flood events occur periodically, as along large rivers or reservoirs, a low levee that is submerged quickly and uniformly receives less flood damage than a large protective levee (Fredrickson and Taylor 1982; Kelley et al. 1993).

Interior levees

Ideally, interior levees should be constructed to the same specifications as exterior levees, but this is not essential. Smaller, temporary levees, often referred to as rice dikes, can be constructed with a rice dike plow, terrace plow, fire plow, bulldozer, or road grader. Those constructed with a rice

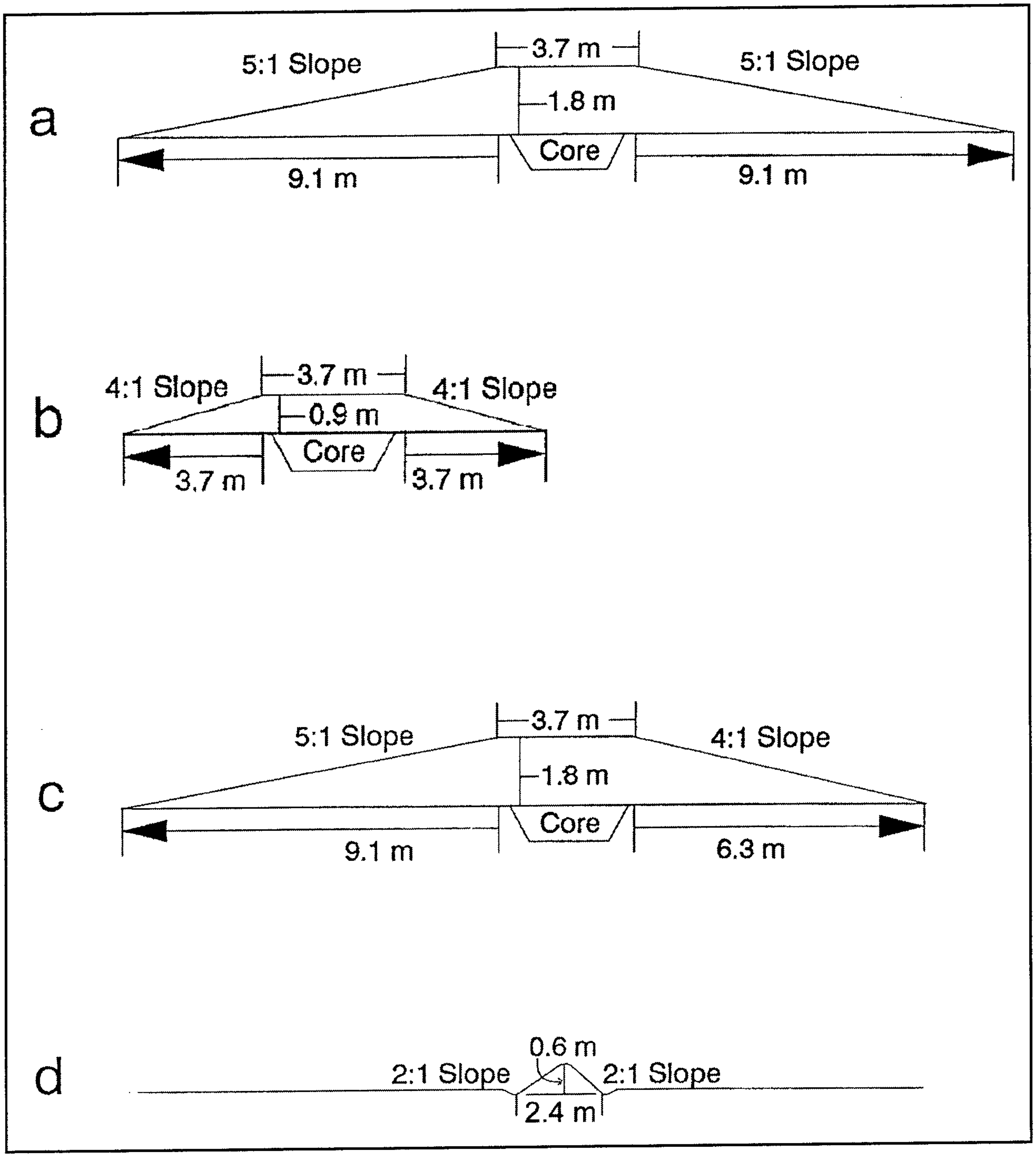

Figure 2. Levee dimensions for a (a) permanent or semipermanent impoundment; (b) seasonally flooded impoundment; (c) header ditch; and (d) rice dike (Kelley et al. 1993)

dike plow typically have steep sides, a base width of approximately 2.5 m (8 ft), and a height of approximately 0.5 m (1.5 ft) (Figure 2). Exact dimensions of completed rice dikes vary with soil type and construction equipment. Rice dikes are susceptible to wave action, require frequent repairs and annual maintenance, and have a functional span of about 2 years (Fredrickson and Taylor 1982; Kelley et al. 1993).

Inner levees should be constructed on contours. Fredrickson and Taylor (1982) recommended a 15-cm (6-in.) contour interval when possible to allow maximum water-level control. During dry years when impoundments must be flooded by pumping, the highest contour level can be flooded first. This reservoir of water plus some additional pumping can then be used to flood the lower levels as dictated by increased wildlife requirements.

Levee placement

Levee placement should be compatible with existing topography. Interior levees should be built on contours, which can be precisely located utilizing precision survey techniques. Interior levees built on 15-cm (6-in.) contour intervals facilitate efficient and precise water control over an entire impoundment. Levees should be seeded with nonwoody vegetation to secure soil and reduce erosion. Mixtures of cool-season grasses, warm-season grasses, or both are recommended for seeding levees. The suitability of grass species for seeding differs according to location and management objectives; advice on appropriate species is available from local agricultural extension offices. Periodic inspections and regular mowing will be required to prevent the establishment of woody vegetation (Fredrickson and Taylor 1982; Payne 1992; Kelley et al. 1993).

Water-Control Structures

Properly designed water delivery, control, and discharge systems are critical for precise control of hydrologic regimes. These systems are necessary to (a) stimulate germination of desirable plants, (b) control nuisance vegetation, and (c) create habitat conditions that encourage wildlife use. Engineers should be employed to design these systems (Kelley et al. 1993).

Water control (i.e., depth and rate of delivery and discharge) is facilitated by water-control structures. The correct placement and design of water-control structures is essential, and control structures should be installed on all major interior and exterior levees. The number and exact locations of structures should be determined by impoundment design and topography. To permit complete inundation, structures regulating water delivery should be located at the highest elevation point of an impoundment. A screw-gate water-control structure may be used to regulate flow into an impoundment. Structures regulating water discharge should be of adequate size and situated at appropriate elevations to permit complete and rapid dewatering of an impoundment. An emergency spillway, placed near the water-discharge structure and 30 cm (12 in.) below the levee top, will allow excess water to drain during flash-flood events (Fredrickson and Taylor 1982; Payne 1992; Kelley et al. 1993).

Stoplog water-control structures are the most effective discharge devices because the design permits precise manipulations of water levels with a minimum of monitoring. New inexpensive stoplog structures constructed from polyvinyl chloride (PVC) pipe are now available and may significantly reduce purchasing costs for water-control structures (Watkins 1992). Screw gates are not appropriate for water-level control because they do not allow precise water manipulations and require constant monitoring during drawdowns (Fredrickson and Taylor 1982; Kelley et al. 1993).

Water-Delivery Systems

To facilitate flooding, a water-delivery system should connect the water source to the impoundment. Three types of water-delivery systems can be used to flood a complex of impoundments (Figure 3). A stair-step overflow flooding system allows water to enter at the highest elevation and flood the highest unit first. As flooding continues, connected units at lower elevations are flooded. This system permits water to flow through impoundments, effectively removing salts and irrigating vegetation. A disadvantage of the stair-step system is that it does not facilitate independent water control for units within a complex.

A header-ditch flooding system (Figure 3) requires construction of a ditch adjacent to the impoundment with water-control structures for each unit. However, PVC pipe may be used instead of a ditch because it allows more efficient use of water, never requires vegetation control, and reduces nuisance rodent encounters. The pipe should be buried to prevent deterioration, and an engineer should be consulted to determine pipe size and elevation gradient. This system is more expensive to develop but permits independent water control for each unit, thus allowing separate management treatments. A third type of water-delivery system utilizes a portable pump and a hose or pipe to transfer water from the source to each unit. This system permits independent flooding of units but requires frequent monitoring (Reid et al. 1989; Kelly et al. 1993).

A gravity-operated water-delivery system is ideal, but pumping is often required if the source is groundwater. Electricity is the most economical power source, followed by diesel, bottled gas, and gasoline. Of greater importance, however, is the availability of a service technician and pump replacement parts. Diesel- and electric-powered pumps are the most common types of pump. Diesel pumps are less expensive to purchase and cost less to install but are expensive to maintain, require frequent monitoring, and are noisy. Electric pumps are more expensive and may require an initial hook-up fee and annual start-up charge, but these need less

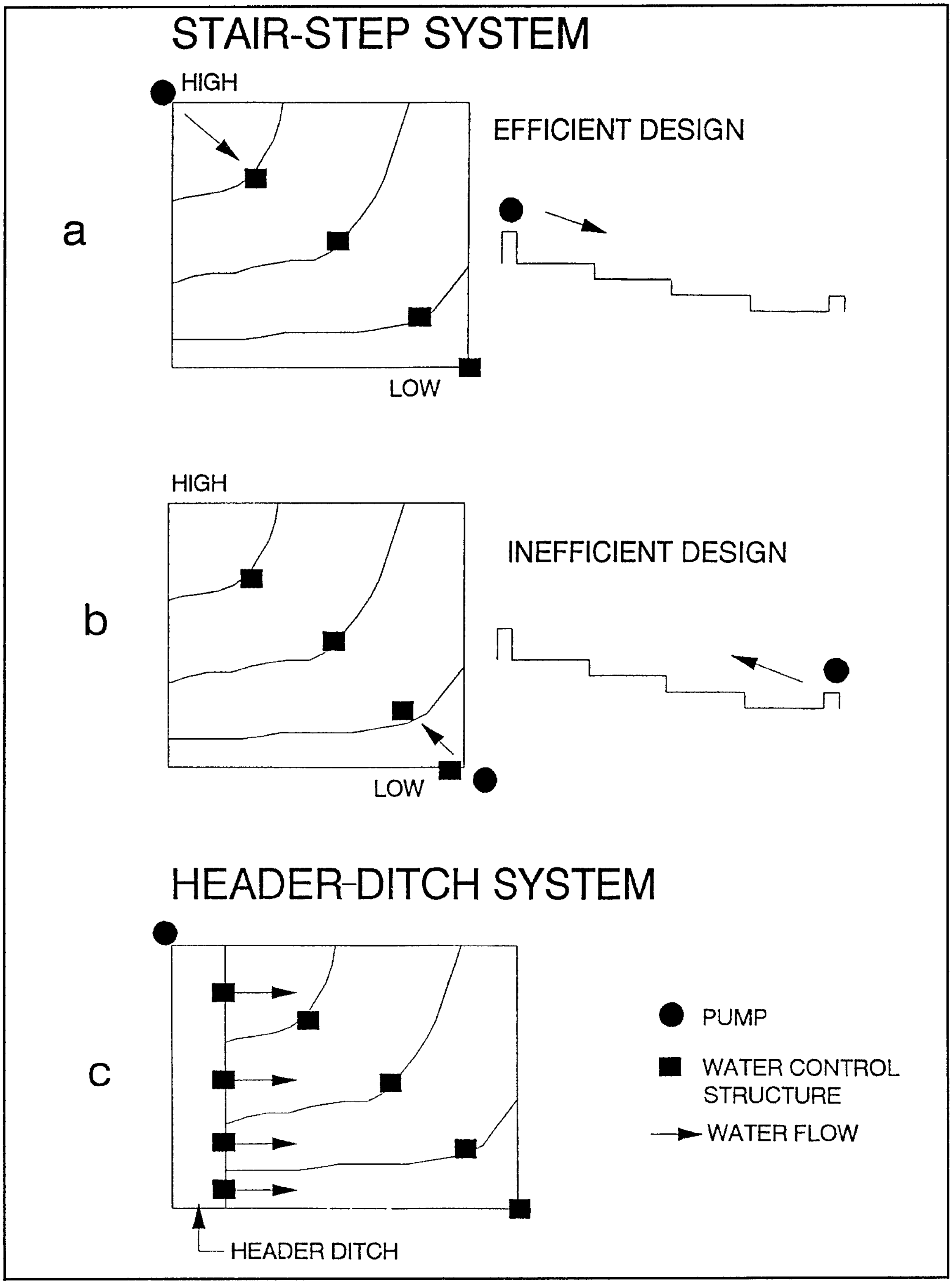

Figure 3. Configuration of water-delivery systems: (a,b) stair-step and (c) header-ditch (Kelley et al. 1993)

maintenance and monitoring and run quietly. A skilled mechanic will be required to service pumps. Most pumps are one of three designs: propeller, mixed-flow, or centrifugal. An engineer should be consulted to determine suitable pump design and size (Reid et al. 1989; Payne 1992).

The water discharge system must facilitate rapid and complete removal of water from all units. Drainage ditches should be a minimum of 0.5 m (1.5 ft) below the base elevation of an impoundment. The exact dimensions and required number of drainage ditches are determined by the volume of water to be removed from an impoundment. Complete removal of water from drainage ditches is necessary to prevent establishment of undesirable vegetation, which reduces drainage capacity. A ditch with a side slope of 4:1 permits equipment access for maintenance. Pumps can be used to remove water from impoundments but increase operating costs (Reid et al. 1989; Payne 1992; Kelly et al. 1993).

4 Management

The objectives of moist-soil management are to (a) maximize production of desirable vegetation; (b) control growth of undesirable vegetation; and (c) provide the required habitat parameters for a variety of wildlife species. Techniques to manipulate hydrology and succession are utilized to manage moist-soil impoundments. The same manipulations are often used to achieve different objectives and should be integrated into an overall management plan. Because of the dynamic nature of moist-soil management, managers must gain an understanding of the biology and interplay between wildlife and moist-soil ecosystems and spend the necessary amount of time on each moist-soil area to make effective management decisions (Fredrickson and Taylor 1982).

Vegetation Management

Plants occurring on moist-soil areas are classified as either desirable or undesirable based on their value for wildlife (Fredrickson and Taylor 1982). Plants that provide cover, energy, or nutritive requirements for wildlife are considered desirable. Plants that do not provide these values, or quickly develop monocultures and impede production of desirable plant species, are considered undesirable (Fredrickson and Reid 1988b). Some species considered undesirable as seed producers may be desirable as habitat for invertebrates. Therefore, each species should be evaluated on its values for wildlife, whether these are direct or indirect. The ability to identify plant species, especially seedlings, and knowledge of their life cycles and wildlife use are critical for making timely decisions to manage moist-soil vegetation (Fredrickson and Taylor 1982). Characteristics of selected moist-soil plants are given in Table 2. Some common moist-soil plant species are described and illustrated in Fredrickson and Taylor (1982). Combs and Drobney (1991) provide a nontechnical reference on aquatic and wetland plants of Missouri with a key, based on stem and leaf characteristics, that will facilitate field identification of wetland plants. Additionally, the Waterfowl Management Handbook (U.S. Fish and Wildlife Service 1988) includes several leaflets discussing moist-soil ecology and habitat management.

Table 2
Characteristics of Selected Moist-Soil Plants, Including Food and Habitat Value, Life Cycle, Germination Dates, Successional Stage, and Potential Seed Production

Plant	Value[1]		Life Cycle		Germination			Successional Stage		Best Seed Production						
										Drawdown				Moisture		
	Food	Habitat	Annual	Perennial	Early	Mid	Late	Early	Late	Early	Mid	Late	None	Dry	Moist	Wet
Pondweeds	+	0		X									X			
Common burhead	+	+		X		X			X						X	X
Sprangletop	+	+	X				X	X				X			X	
Rice cutgrass	+	+		X					X		X	X				X
Crabgrass	+	+	X					X			X	X		X		
Panicum	+	+	X					X			X	X		X		
Common barnyard grass	+	+	X		X	X		X		X	X				X	
Barnyard grass	+	+	X			X	X	X			X	X			X	
Broomsedge bluestem	0	+		X			X		X					X		
Redroot flatsedge	+	+	X				X	X				X				X
Spikerush	+			X	X	X	X	X	X	X	X	X			X	
Beakrush	+	+		X			X		X						X	X
Fox sedge	+	+		X			X		X						X	
Common rush		+		X			X		X	X					X	X
Poverty rush		+		X			X		X	X					X	X
Black willow	0	0		X	X			X		X					X	
Curly dock	+			X	X	X		X		X				X		
Pennsylvania smartweed	+	+	X		X		X	X		X					X	
Curltop ladysthumb	+	+	X		X		X	X		X					X	
Marsh purslane	+			X	X			X	X		X	X	X		X	X
Red ash	+			X				X							X	
Swamp milkweed		+		X			X		X			X			X	
Morning glory	+		X			X	X		X		X	X		X	X	

[1] A plus sign indicates substantial value, and a zero indicates little or no value, as food or habitat. Source: Fredrickson and Taylor (1982).

(Continued)

Table 2 (Concluded)

	Value1		Life Cycle		Germination			Successional Stage		Best Seed Production						
										Drawdown				Moisture		
Plant	Food	Habitat	Annual	Perennial	Early	Mid	Late	Early	Late	Early	Mid	Late	None	Dry	Moist	Wet
Lippia				X		X		X			X			X	X	
Trumpet creeper	0	0		X					X					X	X	
Buttonweed	+			X		X		X			X	X			X	
Common buttonbush	+	+		X					X			X				X
Joe-pye weed	0	+		X			X		X		X			X		
Aster	0	+	X	X			X		X					X		
Common ragweed	+			X		X	X	X			X			X		
Common cocklebur	0	+	X			X	X	X			X	X			X	
Beggarticks	+		X	X		X	X	X			X	X		X	X	
Sneezeweed	0			X		X	X		X		X	X		X	X	

Three important factors that determine species composition, density, and seed production of moist-soil plants at a site are soil seed banks, drawdown and flooding characteristics, and successional stage of vegetation (Kadlec 1962; Meeks 1969; Knauer 1977; van der Valk and Davis 1978; Fredrickson and Taylor 1982; Kelley 1986). These factors are discussed below in further detail.

Soil seed banks

Soil seed banks (residual seeds present in the soil) determine the composition of plant species that pioneer moist-soil sites. Seed banks of most soils, especially fertile alluvial soils, contain abundant stocks of moist-soil plant seeds native to a locality. These seeds may remain viable in the soil for many years, then germinate and produce stands of vegetation under suitable environmental conditions. This is true even if past land use included row cropping. Species composition and abundance of seeds in the soil is related to previous species composition and seed production at a site. Therefore, a moist-soil site with a stand of desirable vegetation will likely produce similar vegetation the following year if environmental conditions are similar. The same probability applies to undesirable vegetation; therefore, suitable techniques must be employed to control their germination, maturation, and reproduction (Fredrickson and Taylor 1982).

Although past agricultural activities do not preclude vegetation management, residual herbicide concentrations may have a negative effect on some moist-soil vegetation. The degree of such effects is dependent on chemical type, application rate, concentration, and time elapsed since last application. Maximum production should not be expected on these sites until herbicides decompose or flush from the soil (Fredrickson and Taylor 1982).

Despite the long-term viability of moist-soil plant seeds, soil seed banks may be inadequate or nonexistent at sites of extreme perturbance (e.g., where topsoil has been removed or deeply covered), in wetlands that have experienced prolonged inundation and lack of emergent vegetation for many years, or in areas where wetlands did not previously occur (e.g., upland sites) (Weller 1990). In these situations, soil seed bank establishment is critical to successful management. Methods used to establish soil seed banks include the transplantation of wetland plant propagules (i.e., seeds, tubers, rootstocks, rhizomes, cuttings, sprigs, and seedlings) and transfer of soil seed banks from another wetland site (Payne 1992). Measures should be taken to minimize impacts when establishing a soil seed bank. U.S. Army Engineer Waterways Experiment Station (1992) lists commercial sources of wetland plant propagules. Obtaining soils or plant propagules from natural sites may require a Federal, State, or local permit from the applicable agency (Payne 1992).

Drawdown and flooding

Timing and duration of annual drawdowns influence moist-soil plant species diversity, density, and seed production. Timing refers to the period when water is removed from a moist-soil site and is termed early, mid, or late. In southeastern Missouri, early drawdowns occur before 15 May; mid drawdowns occur from 15 May to 1 July; and late drawdowns are after 1 July. Drawdown dates are related to growing season duration and vary with latitude, as do vegetative responses (Table 3). In southeastern Missouri, early drawdowns promote higher seed production and result in smartweeds, rushes, and common barnyard grass. Mid-season drawdowns stimulate production of millets, panic grasses, beggarticks, rice cutgrass, hairy crabgrass, and common burhead. Late-season drawdowns promote higher stem densities and greater species diversity and also result in panic grasses, hairy crabgrass, beggarticks, sprangletop, barnyard grass, and redroot flatsedge (Fredrickson and Taylor 1982).

The two types of drawdown based on duration (slow and fast) produce different results. Slow drawdowns drain impoundments over a period of ≥2 weeks and create variable soil conditions. Fast drawdowns drain impoundments within a few days, creating similar soil conditions over the entire impoundment. Slow drawdowns early in the season result in greater species diversity. Fast drawdowns produce lush, extensive stands of similar vegetation, but rapid dewatering forces wetland wildlife from the area almost immediately. Late in the season when soils dry quickly, slow drawdowns tend to produce vegetation of greater density and diversity than fast drawdowns because soils along the receding water line remain saturated longer and allow seeds to germinate. Fast drawdowns late in the season result in less desirable vegetation. This is more pronounced when temperatures exceed 32 °C (90 °F) and where rainfall is required for flooding because saturated soils dry within a few days and little germination occurs (Fredrickson and Taylor 1982).

Reflooding of impoundments should not occur until after desirable plant species have germinated and attained a height of 10 to 15 cm (4 to 6 in.). Shallow flooding (2 to 5 cm, 1.5 to 2 in.) of newly established barnyard grasses, sedges, and smartweeds stimulates rapid growth; however, panic grasses, crabgrasses, and beggarticks are less tolerant. Desirable vegetation should not be completely submerged. Complete submergence of plants for longer than 2 to 3 days can retard growth; therefore, water levels must be lowered if the majority of desirable species do not reach the surface within 3 days. As the desired plant species grow, water levels can be increased gradually to a maximum depth of 15 to 20 cm (6 to 8 in.) but should generally equal about one-third the total height of newly established plants. If plants develop a light-green coloration, water levels are probably too deep and should be lowered immediately (Fredrickson and Taylor 1982).

Table 3
Plants Resulting from Drawdowns in Wetlands Managed for Moist-Soil Vegetation in the United States

Location	Time of Drawdown	Plants	Source
Tennessee	Late April to early May	Smartweed and millet	Barstow (1963)*
South Atlantic and Gulf Coasts	February to March	Smartweed	Baldwin (1967)*
	Late summer	Dwarf spikerush	
Southern Coastal Marshes	Spring or early summer	White waterlily, spikerush, watershield, duckweed, widgeongrass (brackish water)	Chabreck et al. (1989)
North Carolina	April	Dwarf spikerush, smartweed, fall panic grass	Johnson and Montalbano (1989)
South Carolina	February to March	Redroot, smartweed, panic grass, flatsedge	Prevost (1987)*
	Spring	Smartweed, panic grass, millet, flatsedge	Morgan et al. (1975)*
	Summer	Smartweed and millet	Landers et al. (1976)*
Georgia	January, May, and June	Panic grass, spikerush, smartweed	Larimer (1982)*
Louisiana	May	Spikerush, paspalum	Carney and Chabreck (1977)*
Florida	February	Watershield	Tarver (1980)*
	February	Spikerush, smartweed, millet	Holcomb and Wegener (1971)*
	March	Spikerush	Worth (1983)*
Great Lakes Marshes	Early May to June	Nodding smartweed, millet, nutsedge	Bookhout et al. (1989)
N. Great Plains	May or early June	Beggarticks, smartweeds, wild buckwheat, pigweed, goosefoot, kochia	Pederson et al. (1989)
Playa Lakes*	Early April	Smartweeds, curly dock, millets, spikerushes	Haukos and Smith (1993)
	Mid to late June		
	Early August		
Northwest	Late May and June	Smartweeds, beggarticks, goosefoot, kochia	Ball et al. (1989)
	Spring	Foxtail barley	
Great Basin	March	Red goosefoot, smartweed	Kadlec and Smith (1989)
California Valleys	January and March	Dock, slender astor, smartweed	Heitmeyer et al. (1989)
	April and May	Prickle grass, swamp timothy, watergrass	
	May and June	Tule bulrush, cattail, cocklebur, alkali bulrush	

Notes:
* in Johnson and Montalbano (1989)
Source: Johnson and Montalbano (1989)

Managing successional stage

The successional (seral) stage of an impoundment influences plant species composition and seed production. Moist-soil plant communities are typically early seral stages dominated by annual grasses and sedges (Gleason 1917; van der Valk 1981). Succession progresses to later stages after a moist-soil impoundment has been managed for ≥4 years with a similar water regime and no soil disturbances (Fredrickson and Taylor 1982). Early successional stages result in plant species with high seed production, but annuals decline in later successional stages and are eventually replaced by perennial plant species (Reid et al. 1989). Although some perennials are good seed producers, undesirable species tend to become dominant, and monocultures of perennial or woody species develop in later successional stages. Therefore, procedures to set back succession are required to maintain habitat quality and high seed production (Fredrickson and Taylor 1982).

Techniques used to set back succession include water manipulation, burning, and mechanical disturbances (Reid et al. 1989). Deep flooding of impoundments can be used to kill dense stands of undesirable wetland vegetation and shift succession to an earlier stage (Payne 1992). Controlled burning of impoundments will alter vegetative structure and composition, improve plant vigor and nutrition, and create openings in dense stands of emergent vegetation. Burning is a common practice used in southern coastal regions to reduce excessive accumulation of plant litter, which inhibits growth of desirable vegetation, and set back succession. Burns should be performed in early spring while vegetation is dry and before new vegetation has emerged (Fredrickson and Taylor 1982). Common mechanical procedures used to set back succession include mowing, disking, crushing, and bulldozing (Reid et al. 1989). Disking is the most common soil disturbance technique utilized in moist-soil impoundments. Dewatering must occur early enough to allow sufficient drying of the substrate for operation of machinery within the impoundment. Impoundments should be disked once every 3 years to stimulate seed production of annuals and control woody growth. However, an impoundment that has been under moist-soil management for 5 to 7 years may not need disking as often because of changes in soil conditions and seed availability (Fredrickson and Taylor 1982).

Gray (1995) studied the responses of moist-soil plants to mechanical treatments (tilling, disking, and mowing) at Noxubee National Wildlife Refuge in north Mississippi and found that tilling (cultivation) produced the greatest seed yields, plant species diversity, and frequency of grasses and legumes. Kaminski et al. (1995) found that aquatic invertebrate biomass was 1.3 to 3.5 times greater on tilled plots and that disking resulted in the second greatest response to all these factors. Disking is more economical than tilling and may be more effectively used for large-scale management. Performing multiple passes or using disks 60 cm (24 in.) in diameter will increase soil disturbance (Kelley 1986) and probably create conditions similar to tilling (Gray 1995). Mowing prior to disking will allow disks to more effectively scarify the soil. Vegetation manipulations can be performed in patches and/or sinuous strips to provide an approximate 50:50 ratio of emergent vegetation and open water after flooding, as recommended for greatest waterfowl and waterbird use by Kaminski and Prince (1981) and Prather et al. (1994). However, law enforcement officials should be consulted prior to autumn manipulations if hunting is planned on manipulated areas, as planting in the suggested configurations could be misconstrued as "baiting" (Gray 1995). Autumn tilling or disking may be more cost-effective than biannual manipulations if these procedures eliminate the need for spring or summer water manipulations to revert succession.

Controlling undesirable vegetation

Most undesirable plant species can be controlled by using some of the same techniques that are used to encourage growth of desirable vegetation. Frequent inspections of impoundments are required to determine plant species composition and make timely management decisions that will effectively control undesirable vegetation. Interior levees built on contour intervals of 15 to 20 cm (6 to 8 in.) facilitate shallow flooding of large areas with little water and are optimal for immediate and effective control of undesirable plants (Fredrickson and Taylor 1982).

Timing of reflooding is critical in the control of many undesirable herbaceous plants. After a drawdown, cockleburs and asters germinate earlier than desirable plants. Shallow flooding (1 cm, 0.4 in.) after desirable species are established will inhibit growth of cockleburs and asters (Fredrickson and Taylor 1982). When the root systems and bases of cocklebur are submerged for a period of 24 to 48 hr, the plants will either die or be stunted. Growth increases in response to irrigation of desirable species such as annual grasses, smartweeds, or sedges (Reid et al. 1989). As desirable plants grow, water depths can be increased gradually so that cockleburs are controlled on higher contours before they shade out desirable plants (Fredrickson and Taylor 1982). Broomsedge bluestem can be controlled by shallow flooding (10 cm, 4 in.) until midsummer, and joe-pye weed can be controlled by flooding in late summer when plants are in bloom. Establishment of reed canary grass can be inhibited with high water levels maintained through spring (Ball et al. 1989). Woolgrass can be controlled with an early spring drawdown every 3 to 4 years, deep plowing, and fall flooding (Hindman and Stotts 1989). Big cordgrass can be reduced by flooding depths of 30 to 60 cm (12 to 24 in.) or by salinities of 60 parts per thousand. It can be eliminated by burning or mowing, followed by compaction and flooding (Prevost 1987). Smooth cordgrass can be controlled by a drawdown lasting one growing season and burning to remove dead stems (Gordon et al. 1989).

Purple loosestrife is a hardy, exotic herbaceous perennial that causes management problems in northeastern wetlands that have naturally occurring or artificial drawdowns. The most critical problems occur in the region covered by the Wisconsin glacier, so area managers should be aware of this serious problem before initiating a moist-soil management program (Fredrickson and Taylor 1982). Seedlings can be eradicated by deep flooding for 5 weeks; however, seedlings with terminal growths above the water surface will survive and grow vigorously (Thompson 1989). In northern regions, drawdowns completed before mid-May will reduce germination and promote species that are better adapted to cooler temperatures (Merendino et al. 1990).

Phragmites (common reed) and cattails may cause management problems in some impoundments. When interspersed with open water or other vegetation, these plants provide valuable cover. However, on some sites they form monotypic rank stands and have little value for waterfowl (Cross and Flemming 1989; Sojda and Solberg 1993). Phragmite stands can be almost completely eradicated by mowing, burning, and disking at least twice (Cross and Flemming 1989). The reduction of cattail establishment in northern regions can be achieved by drawdowns in May (Merendino et al. 1990). Established cattails can be controlled by cutting, crushing, shearing, disking, or burning while plants are dormant, in conjunction with spring flooding that covers residual stalks (Sojda and Solberg 1993).

Disking and reflooding should be performed in impoundments with few desirable plants and extensive stands of cockleburs, asters, and other undesirable herbaceous plants. However, not all plants can be controlled by disking and reflooding. Disking plants such as American lotus and yellow water lily, which occur on sites difficult to drain, will cut rhizomes into smaller sections; new shoots may then develop from the rhizomes, which contain internal energy reserves and stem-forming tissue (Fredrickson and Taylor 1982).

Controlling undesirable woody vegetation can be difficult, and techniques vary with latitude. A combination of mechanical disturbance and water manipulation is often utilized. Willows, cottonwoods, and ashes are common species that invade moist-soil impoundments and form dense, extensive stands that shade and eliminate herbaceous undergrowth. At northern sites, late drawdowns and shallow flooding prevent or reduce the establishment of woody vegetation. Seedlings and saplings can be controlled by mowing or disking and shallow flooding. However, shallow flooding at southern sites stimulates growth of woody vegetation. Young seedlings can be eliminated by deep flooding that covers all aboveground growth, but deep flooding may not be possible in some impoundments. A complete drawdown and shallow disking will eliminate newly established seedlings and disrupt root systems of older plants. Saplings 7.5 to 10 cm (3.0 to 4.0 in.) in diameter cannot be effectively disked. Mowing saplings with a bushhog is an alternative; however, root systems are not modified, and multiple shoots will develop from severed trunks. Fall mowing and flooding through the next growing season may effectively control willow saplings. Bulldozing may be the only option for controlling dense stands of stems $\geq$10 cm (4 in.) in diameter, but it is expensive and alters impoundment basins. In these situations, creating openings or increasing the amount of edge while preventing further establishment of woody growth may be less expensive and more practical (Fredrickson and Taylor 1982; Fredrickson and Reid 1988c).

Prescribed burning is used in conjunction with water-level manipulations to control undesirable vegetation in the wetlands of the Chesapeake Bay and North Carolina sounds (Hindman and Stotts 1989). Most marshes are burned annually in late winter to encourage stands of bulrushes and discourage saltgrass and marshhay cordgrass. However, burning is not done during drought periods when the marsh is flooded with salt tides, as the high salinity may cause "scalded" areas that become unproductive mud flats. At McKay Island National Wildlife Refuge, prescribed burning is conducted every 3 years following a hard frost between mid-November and mid-March. Late winter burns have been used at Blackwater National Wildlife Refuge to promote growth of Olney bulrush for lesser snow geese and make seeds of saltmarsh bulrush available to feeding ducks. Early spring burns interfere with nesting dabbling ducks and marsh birds and should not be conducted in this area after the first of March. Hindman and Stotts (1989) recommended constructing fire lanes just inside upland borders of the marsh-upland interface to protect upland food and cover plants.

Herbicides are an alternative to mechanical disturbances and water manipulations for controlling undesirable vegetation. However, the purchase and application of chemicals are usually costly. Chemicals are often restricted in aquatic systems and on public lands, may have detrimental effects on wildlife, and may have residual effects on desirable vegetation that inhibit future plant growth (Fredrickson and Reid 1988c). Therefore, the use of chemicals must be carefully considered. Payne (1992) provides an extensive review of chemical treatments for vegetation management.

Wildlife Management

Management of moist-soil impoundments for wildlife involves the creation of habitat conditions attractive to target wildlife species (Table 4). Because of annual variations in environmental conditions, management manipulations should be based on ecological variations in the life histories of these species rather than on set calendar dates (Fredrickson and Taylor 1982). Impoundments with irregular topography will contain sites of various water depths and habitat conditions attractive to a variety of wildlife species. Water levels are manipulated to equal the optimum foraging depths for different bird groups during fall flooding and seasonal drawdowns. Procedures should be coordinated with the arrival and departure of wildlife species and with changes in local habitat conditions.

Table 4
Habitat Conditions That Attract Vertebrates to Moist-Soil Impoundments

Vertebrate Group	Water Depth, cm	Foods				Openings		Vegetative Cover			
		Vertebrates	Invertebrates	Seeds	Browse	Water	Mud Flat	Rank	Short	Dense	Sparse
Amphibians	0-20		X			X	X		X		X
Reptiles	0-50	X	X			X		X	X	X	X
Grebes	25+	X				X			X		X
Geese	0-10			X	X	X	X		X	X	X
Dabbling ducks	5-25		X	X		X	X	X			
Diving ducks	25+		X	X		X					
Hawks	NA	X							X	X	X
Galliformes	D-M		X	X				X	X	X	X
Herons	7-12	X	X			X			X		X
Rails	5-30		X	X				X	X	X	
Coots	28-33			X	X	X			X		X
Shorebirds	0-7		X			X	X		X		X
Owls	D-M	X							X	X	X
Swallows	NA		X			X			X		X
Sedge wrens	NA		X					X		X	
Nesting passerines	NA		X	X				X	X	X	X
Winter fringillids	NA			X				X	X	X	X
Rabbit	0				X			X		X	
Raccoon	0-10	X	X	X		X	X	X	X	X	X
Deer	0				X			X			

Notes: D-M = dry to moist; NA = not applicable (use is not dependent on flooding or specific water depths). Source: Fredrickson and Taylor (1982).

Optimum foraging depths

Water depths of 10 to 25 cm (4 to 10 in.) are suitable for most dabbling ducks and Canada geese. Mallards usually feed on the bottom, dabbling from the surface in water 10 to 15 cm (4 to 6 in.) deep. Pintails feed on the bottom but tip up in water 15 to 20 cm (6 to 8 in.) deep. Blue-winged teal and green-winged teal prefer water depths of 12 to 20 cm ((5 to 8 in.); blue-winged teal are attracted to sites with submerged vegetation. Northern shovelers strain for invertebrates near the surface of deeper waters but will forage in a variety of water depths. American coots usually dive for food, preferring depths around 30 cm (12 in.). Moist-soil impoundments are usually not managed for diving ducks because the preferred water depths (≥50 cm, 20 in.) exclude most nonwaterfowl species and require substantial, costly levees. Initially, waterfowl respond best to units with some open water but after several days will land directly or swim into rank or dense vegetation (Fredrickson and Taylor 1982).

Wading birds prefer water depths of 7 to 12 cm (3 to 5 in.) and areas with emergent vegetation. Herons are attracted to sites with only sparse emergent vegetation and abundant submerged and floating vegetation. Shorebirds require shallow depths ≤7 cm (3 in.) interspersed with exposed mud flats and enough emergent vegetation for concealment. Longer legged shorebirds frequent deeper water, whereas shorter legged birds use more shallow depths. Rails and snipes are attracted to areas of dense emergent vegetation. Rails use both shallow and deep water but prefer depths of 5 to 10 cm (2 to 4 in.). Snipes use shallow-water areas 1 to 3 cm (0.4 to 1 in.) deep. Passerines will frequent areas of dense cover, but their use is not dependent on flooding or specific water depths.

Water manipulation

During fall and winter, moist-soil impoundments are most frequently managed for waterfowl. However, providing suitable habitat for dabbling ducks creates conditions attractive to many other wildlife species. Fall flooding of impoundments should coincide with the arrival of fall migrants and peak populations. Blue-winged teals and pintails are usually the earliest waterfowl to migrate. Impoundments inundated at this time should contain plants with mature, smaller seeds (e.g., panic grasses and crabgrasses), which are ideal foods for early migrating species. Flooding should progress gradually to maximize the area with water depths not greater than 10 cm (4 in.). As fall advances and waterfowl populations increase, additional units should be flooded to preferred depths to accommodate additional waterfowl species or other bird groups. A realistic management goal is to flood to an optimum foraging depth 85 percent of the surface area of a moist-soil complex by the peak of fall waterfowl migration (Fredrickson and Taylor 1982; Fredrickson 1991).

Management options for drawdowns involve manipulations to provide optimum foraging depths for desired bird groups when they arrive (Fredrickson 1991). Drawdowns expose mud flats nearly devoid of vegetation and concentrate vertebrates and invertebrates, making them available to a variety of wildlife species. Slow drawdowns are recommended because they prolong the period of availability of optimum foraging depths and increase the duration and diversity of bird use. As the first drawdowns near completion and habitat conditions deteriorate, drawdowns can be initiated in other impoundments to maintain wildlife use.

Partial drawdowns in late winter should be timed to coincide with northward movements of early migrating waterfowl. Late winter drawdowns benefit mallards, pintails, wigeons, and Canada geese (Fredrickson 1991). Early to mid-spring drawdowns make resources available for late migrants such as teals, shovelers, rails, and bitterns. Early spring drawdowns should coincide with shorebird migration, which varies with latitude and phenology of the species that nest on or migrate through an area. In southeastern Missouri, lesser yellowlegs and pectoral sandpipers arrive in early to mid-April. After an early spring drawdown, an impoundment is almost devoid of old vegetation, which creates mud flat conditions favored by shorebirds. However, sites within impoundments that were flooded to shallow depths during winter often contain new growths of plants that provide emergent cover, such as spikerushes and old clumps of soft rushes, bulrushes, and stems and blades of grasses and sedges. When drawdowns are late, deeper water sites will contain decaying, submerged, and regenerating vegetation such as marsh purslane, water-starwort, and swamp smartweed, along with scattered emergents. These sites concentrate invertebrates, amphibians, and fish and are optimal for insect production. Thus, wading birds, rails, late migrating or resident waterfowl, and passerines are attracted to these areas (Fredrickson and Taylor 1982).

In areas with breeding waterfowl and wading birds, mid-and late-spring drawdowns should coincide with peak hatch periods and continue during early brood development or nestling growth (Fredrickson 1991). Late spring drawdowns are most effective if completed in two phases. The first phase is timed to coincide with the arrival of herons, rails, swallows, or other bird groups. In southeastern Missouri, late spring drawdowns begin with the arrival of little blue herons and yellow-crowned night herons. Water levels are initially lowered to 5 to 15 cm (2 to 6 in.) and maintained until plants germinate on mud flats. The second phase of a drawdown should begin after germination and continue until water removal is complete (Fredrickson and Taylor 1982).

Early and late-spring drawdowns are both utilized in an optimal moist-soil management program. Impoundments managed to attract herons and rails should stay flooded until early drawdowns are completed and those impoundments are revegetated and able to tolerate reflooding. Late drawdowns can then be completed without permanently displacing wetland wildlife. Herons will be attracted to revegetated and reflooded impoundments (Fredrickson and Taylor 1982).

Areas intended for upland wildlife should not be reflooded until fall if rainfall is sufficient to encourage optimum plant growth. During dry summers, shallow reflooding of impoundments is required to irrigate vegetation. After complete soil saturation, including soils at the highest sites, water can be removed within 1 to 2 hr. If water enters the impoundment at the highest elevation, lower sites can be irrigated with overflow water. Typical vegetation includes asters, ragweeds, beggarticks, crabgrass, and panic grass. However, if extensive growth of undesirable plant species occurs, control of this vegetation overrides management for upland wildlife (Fredrickson and Taylor 1982).

Integrated management

Management of impoundments is designed to promote growth of certain plant species and create habitat conditions for a variety of wildlife species. Wildlife use is related to the structural components of vegetation as well as water depth (Fredrickson and Taylor 1982). Having several impoundments on a management area allows management manipulations to attract different groups of wildlife. Fredrickson and Taylor (1982) developed a flowchart that illustrates management manipulations and resulting conditions based on plant and wildlife responses over a 13-year period at Mingo National Wildlife Refuge (Figure 4). The chart depicts four flooding depths and the seasonal habitat conditions that attract five wildlife groups; namely, waterfowl, herons, rails, shorebirds, and upland wildlife. Each manipulation adjusts the attractiveness of the habitat for the different assemblages of wildlife by creating different combinations of water depth, food, and vegetative cover.

Maintaining a particular condition for extended periods is not desirable because wetland plants and animals are adapted to water fluctuations in natural wetlands. For example, an impoundment is drawn down to a depth of 5 cm (2 in.) in early spring to make waterfowl habitat attractive to shorebirds. The drawdown is completed in summer; if needed, the impoundment is disked to eliminate undesirable vegetation and reflooded to a depth of 5 cm (6 in.). After shorebird migration, water levels are increased to accommodate waterfowl in late fall and winter. Depending upon management needs, a variety of options are available to the moist-soil manager. A number of strategies, including no action, are appropriate in different years to create habitat conditions attractive to wetland wildlife (Fredrickson and Taylor 1982).

Monitoring and Evaluation

Successful moist-soil management requires regular and frequent inspections of impoundments. While impoundments are flooded, weekly inspections are required to examine levees, water-control structures, and pumps, thus ensuring the maintenance of correct water levels. Impoundments

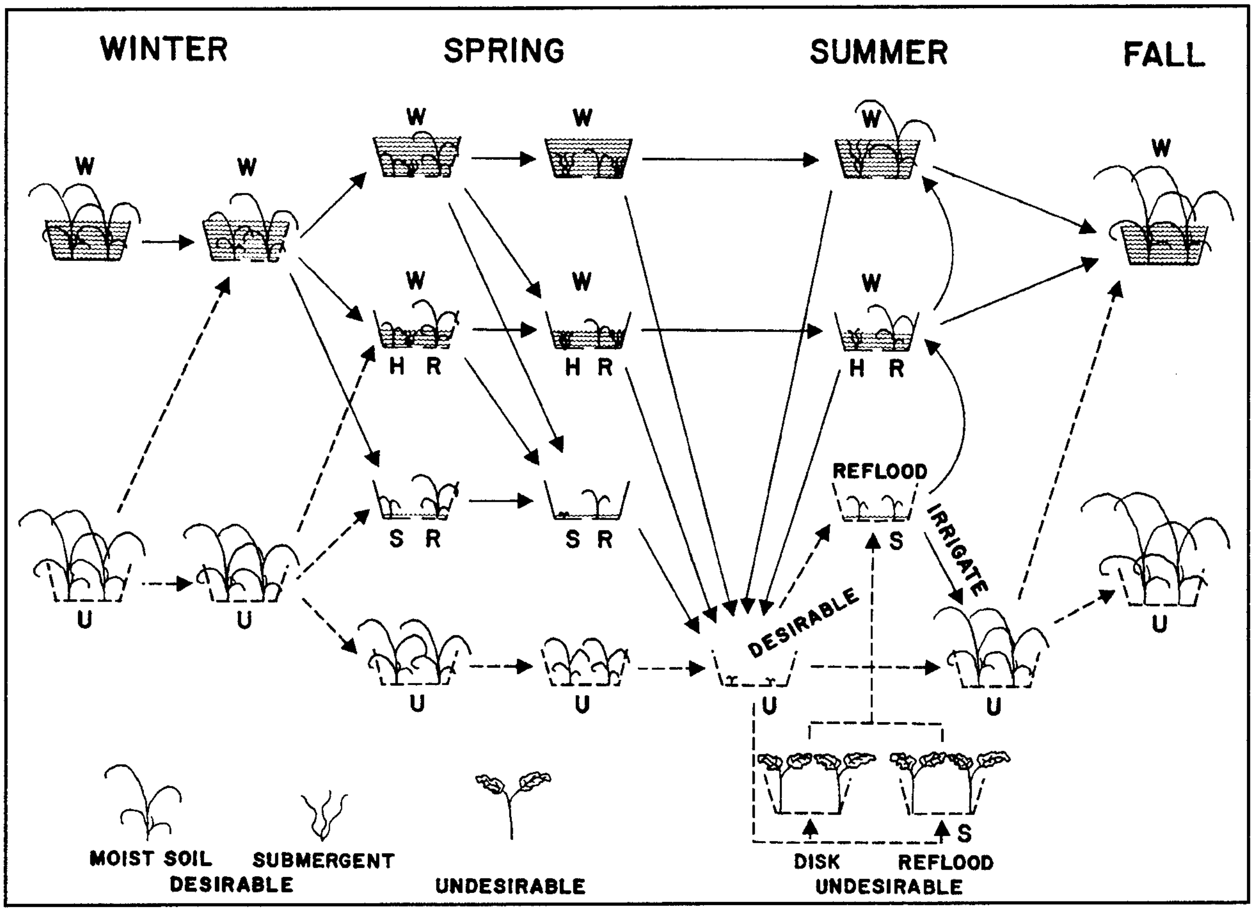

Figure 4. Flow diagram showing manipulations resulting in seasonal habitat conditions that attract five wildlife groups: W (waterfowl), H (herons), R (rails), S (shorebirds), and U (upland wildlife) (Fredrickson and Taylor 1982)

should be inspected more frequently during and after drawdowns to monitor plant germination, composition, and growth. Frequent inspections allow timely management decisions concerning the production and control of vegetation. Periodic surveys of impoundments should be conducted to determine wildlife use and arrival and departure dates. Keeping accurate field records will help with future management decisions and facilitate the continuity of management with changes in personnel. A sample data sheet is shown in Appendix C.

Seed production differs among plant species and varies annually depending on environmental conditions and management practices (Laubhan 1992). Chemical composition, which determines the nutritional content of seeds, also varies among plant species. Therefore, managing for maximum productivity and quality of wildlife foods in moist-soil impoundments requires a knowledge of annual seed production. A technique developed by Laubhan (1992) can be used to estimate seed production of common moist-soil plants. Ideally, vegetation should be sampled each year to determine the amount of seed produced by each plant species in each impoundment. Results of annual seed production surveys can be used to evaluate effects of various management strategies and to determine carrying capacity of food resources within an impoundment; carrying capacity is expressed as potential number of waterfowl use-days (Reinecke et al. 1989; Laubhan 1992). Appropriate sampling schemes, procedures for collecting field data, and computations for estimating seed production are described in Laubhan (1992). This information can also be accessed from an electronic file entitled Moist Soil Management Advisor, developed at the Gaylord Memorial Laboratory, University of Missouri, Columbia. The Moist Soil Management Advisor is located on the Internet at the U.S. Geological Survey web site (*www.mesc.usgs.gov/msma/*). Sampling instructions and data sheets are given in the User's Guide provided by the Advisor. Additional moist-soil management information and links to other web sites can also be found here.

5 Labor and Costs

The initial development of moist-soil impoundments is expensive but is comparable with the development of agricultural fields flooded to attract wildlife. However, moist-soil management is more economical because money and energy are used more efficiently, especially on sites where flooding inhibits consistent production of row crops. Operational costs associated with moist-soil management are primarily related to general impoundment maintenance and sustaining plant communities in early successional stages (Fredrickson and Taylor 1982).

High capital investment in the development of moist-soil impoundments is attributed to consulting fees, levee construction, and the purchase of pumps, water-control structures, and machinery. Developmental costs vary widely, ranging from approximately $500 to $37,000 per ha ($200 to $15,000 per acre), depending on specific situations. Ducks Unlimited, Inc., attempts to maintain costs below $1,250 per ha ($500 per acre). Costs surpassing this figure may indicate problems associated with planning or may be justified by special circumstances, such as critical habitat needs or threatened and endangered species protection.[1] Consulting fees vary and must be considered during planning.

Levee construction is expensive; costs are highly variable and depend mainly upon impoundment size, levee dimensions, number of contour levees, amount of fill material, and special construction needs. Costs for water-control structures vary with design and size. New, inexpensive stop-log structures constructed from PVC pipe are now available and may significantly reduce purchasing costs (Watkins 1992). Prior to levee construction or placement of water-control structures, a detailed hydrological study should be performed on the site. This will provide critical information for the proper placement and design of levees and water-control structures. Experienced and reputable engineering and construction firms should be employed to ensure quality design and construction.

1 Personal Communication, F. A. Reid, Ducks Unlimited, California.

The variation in pump purchase costs is relative to pump design, size, and power source. Decisions on pump purchases are often made only on the basis of initial costs (Reid et al. 1989). Reid et al. (1989) developed a 25-year scenario to compare long-term pumping costs among three pump types. One-phase electric, three-phase electric, and diesel pumps were compared with respect to documented maintenance, energy, and repair analyses. Three-phase electric pumps are initially the most costly and will remain the most costly if annual start-up fees are charged. One-phase electric pumps do not require an initial line fee, and estimated maintenance cost is low. However, one-phase electric pumps have only been tested for a few years, and early evidence indicated a need for extensive repairs or replacement. Initial purchase price for diesel pumps is the least costly, but maintenance costs are highest. Overhaul of diesel engines is required approximately every 4 years or every 4,500 hr of use. Long-term pump costs will vary according to fuel prices, repair and maintenance, and specific situations; however, long-term cost assessment should be considered during initial pump selection (Reid et al. 1989).

Costs for moist-soil impoundments are considerably less than row crop investments and can be as low as 5 percent of corn investments. Major cost differences are related to labor, machinery, fuel, annual seeding, and applications of fertilizer, herbicides, and insecticides that are required for successful row crop production (Fredrickson and Taylor 1982; Reid et al. 1989). Procedures to modify succession and control undesirable vegetation are major costs associated with moist-soil management. Whenever possible, these physical disturbances may be performed by lessee farmers in exchange for farming rights, but supervision is required to ensure the achievement of management goals. This reduces operational as well as purchasing costs for implements. Opportunities may also be available for partnering with agencies such as the U.S. Fish and Wildlife Service, the State natural resources department, and the Natural Resource Conservation Service, or organizations such as Ducks Unlimited, Inc.

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Appendix A
Common and Scientific Names of Animal Species Named in Text (listed alphabetically by major groups)

Common Name	Scientic Name	Common Name	Scientific Name
	Water Fowl		
American black duck	*Anas rubripes*	Mallard	*Anas platyrhynchos*
American wigeon	*Anas americana*	Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*	Northern pintail	*Anas acuta*
Canada goose	*Branta canadensis*	Ring-necked duck	*Aythya collaris*
Gadwall	*Anas strepera*	Snow goose	*Chen caerulescens*
Green-winged teal	*Anas crecca*	Tundra swan	*Cygnus columbianus*
Hooded merganser	*Lophodytes cucullatus*	Wood duck	*Aix sponsa*
	Wetland/Wading Birds		
American bittern	*Botaurus lentiginosus*	Least sandpiper	*Calidris minutilla*
American coot	*Fulica americana*	Lesser yellowlegs	*Tringa flavipes*
Black-crowned night heron	*Nycticorax nycticorax*	Little blue heron	*Egretta caerula*
Cattle egret	*Bubulcus ibis*	Pectoral sandpiper	*Calidris melanotos*
Common moorhen	*Gallinula chloropus*	Pied-billed grebe	*Podilymbus podiceps*
Dunlin	*Calidris alpina*	Snowy egret	*Egretta thula*
Great egret	*Casmerodius albus*	Solitary sandpiper	*Tringa solitaria*
Great blue heron	*Ardea herodius*	Sora	*Porzana carolina*
Greater yellowlegs	*Tringa melanoleuca*	Spotted sandpiper	*Aetitus macularia*
Green-backed heron	*Butorides striatus*	Virginia rail	*Rallus limicola*
Killdeer	*Charadrius vociferus*	Willet	*Catoptrophorus semipalmatus*
King rail	*Rallus elegans*	Yellow-crowned night heron	*Nycticorax violaceus*
Least bittern	*Ixobrychus exilis*		

Common Name	Scientic Name	Common Name	Scientific Name
Game Birds			
American woodcock	*Scolopax minor*	Northern bobwhite	*Colinus virginianus*
Common snipe	*Gallinago gallinago*	Ring-necked pheasant	*Phasianus colchicus*
Mourning dove	*Zenaida macroura*	Wild turkey	*Meleagris gallopavo*
Raptors			
Bald eagle	*Haliaeetus leucocephalus*	Northern harrier	*Circus cyaneus*
Barn owl	*Tyto alba*	Red-shouldered hawk	*Buteo lineatus*
Barred owl	*Strix varia*	Red-tailed hawk	*Buteo jamaicensis*
Golden eagle	*Aquila chrysaetos*	Short-eared owl	*Asio flammeus*
Great horned owl	*Bubo virginianus*		
Passerines			
American goldfinch	*Carduelis tristis*	Indigo bunting	*Passerina cyanea*
American crow	*Corvus brachyrhynchos*	Marsh wren	*Cistothorus palustris*
Bank swallow	*Riparia riparia*	Red-winged blackbird	*Agelaius phoeniceus*
Barn swallow	*Hirundo rustica*	Sedge wren	*Cistothorus platensis*
Belted kingfisher	*Ceryle alcyon*	Song sparrow	*Melospiza melodia*
Chimney swift	*Chaetura pelagica*	Swamp sparrow	*Melospiza georgiana*
Common nighthawk	*Chordeiles minor*	Tree swallow	*Tachycineta bicolor*
Common yellowthroat	*Geothylpis trichas*	White-crowned sparrow	*Zonotrichia leucophrys*
Dickcissel	*Spiza americana*	White-throated sparrow	*Zonotrichia albicollis*
Eastern kingbird	*Tyrannus tyrannus*		
Mammals			
Muskrat	*Ondatra*	Raccoon	*Procyon lotor*
Mink	*Mustela vison*	White-tailed deer	*Odocoileus virginianus*
Rabbits	*Sylvilagus* spp.		

Appendix B
Common and Scientific Names of Plant Species Named in Text (listed alphabetically)

Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
Alkali bulrush	*Scirpus robustus*	Common rush	*Juncus effusus*
American bulrush	*Scirpus americanus*	Corn	*Zea mays*
American lotus	*Nelumbo lutea*	Cottonwood	*Populus* spp.
Arrowhead	*Sagittaria* spp.	Crabgrass	*Digitaria* spp.
Aster	*Aster* spp.	Cultivated rice	*Oryza sativa*
Barnyard grass	*Echinochloa crusgalli* var. *mitis*	Curltop ladysthumb	*Polygonum lapthifolium*
Beakrush	*Rynchospora* spp.	Curly dock	*Rumex crispus*
Beggarticks	*Bidens* spp.	Dock	*Rumex* spp.
Big cordgrass	*Spartina cynosuroides*	Duck potato	*Sagittaria latifolia*
Black willow	*Salix nigra*	Dwarf spikerush	*Eleocharis parvula*
Blunt spikerush	*Eleocharis obtusa*	Fall panic grass	*Panicum dichotomiflorum*
Broomsedge bluestem	*Andropogon virginicus*	Flatsedge	*Cyperus* spp.
Bulrush	*Scirpus* spp.	Fox sedge	*Carex vulpinoidea*
Buttonbush	*Cephalanthus occidentalis*	Foxtail barley	*Hordeum jubatum*
Buttonweed	*Diodia virginiana*	Goosefoot	*Chenopodium* spp.
Carolina redroot	*Lachnanthes caroliniana*	Hairy crabgrass	*Digitaria sanguinalis*
Cattails	*Typha* spp.	Horned beakrush	*Rynchospora corniculata*
Chufa flatsedge	*Cyperus esculentus*	Indigobush amorpha	*Amorpha fruticosa*
Cocklebur	*Xanthium* spp.	Joe-pye weed	*Eupatorium purpureum*
Common barnyard grass	*Echinochloa crusgalli*	Kochia	*Kochia scoparia*
Common burhead	*Echinodorus cordifolius*	Lippia	*Lippia lanceolata*
Common buttonbush	*Cephalanthus occidentalis*	Marsh purslane	*Ludwigia* spp.
Common cocklebur	*Xanthium strumarium*	Millet	*Echinochloa* spp.

Common Name	Scientific Name	Common Name	Scientific Name
Common duckweed	*Lemna minor*	Marsh swampweed	*Polygonum coccineum*
Common ragweed	*Ambrosia artemisiifolia*	Milo	*Sorghum vulgare*
Common reed	*Phragmites communis*	Morning glory	*Ipomoea coccinea*
Nodding smartweed	*Polygonum lapathifolium*	Smooth cordgrass	*Spartina alterniflora*
Nutsedge	*Cyperus* spp.	Sneezeweed	*Helenium flexuosum*
Panic grass/Panicum	*Panicum* spp.	Spikerush	*Eleocharis smallii*
Paspalum	*Paspalum* spp.	Sprangletop	*Leptochloa fasicularis*
Pennsylvania smartweed	*Polygonum pensylvanicum*	Squarestem spikerush	*Eleocharis quadrangulata*
Pigweed	*Amaranthus* spp.	Swamp milkweed	*Asclepias incarnata*
Pondweeds	*Potamogeton* spp.	Swamp smartweed	*Polygonum hydropiperoides*
Poverty rush	*Juncus tenuis*	Swamp timothy	*Heleocloa schenoides*
Prickle grass	*Crypsis niliaca*	Tooth-cup	*Ammannia coccinea*
Purple loosestrife	*Lythrum salicaria*	Trumpetcreeper	*Campsis radicans*
Ragweed	*Ambrosia* spp.	Tule bulrush	*Scirpus acutus*
Red goosefoot	*Chenopodium rubrum*	Water grass	*Echinochloa* spp.
Red ash	*Fraxinus pennsylvanica*	Watershield	*Brasenia schreberi*
Redroot amaranth	*Amaranthus retroflexus*	Water-starwort	*Callitriche heterophylla*
Redroot flatsedge	*Cyperus erythrorhizos*	White waterlily	*Nymphaea tuberosa*
Reed canary grass	*Phalaris arundinacea*	Widgeongrass	*Ruppia maritima*
Rice cutgrass	*Leersia oryzoides*	Wild buckwheat	*Polygonum convovulus*
Slender aster	*Aster exilis*	Woolgrass	*Scirpus cypernus*
Smartweed	*Polygonum lapathifolium*	Yellow waterlily	*Nuphar luteum*

Appendix C Data Sheet for Moist-Soil Manipulations (Fredrickson and Taylor 1982)[1]

Data Sheet for Moist-Soil Manipulations

Impoundment Number		Year	
Type of Manipulation:	(1) Winter	(4) Summer	
	(2) Early Spring	(5) Early Fall	
	(3) Late Spring	(6) Late Fall	
Notes on Manipulation:			
Date	Water level	Stoplog elevation	Notes
Animal response:			
Species	Arrival	Departure	Notes

[1]References cited in this appendix are listed in References at the end of the main text.

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This report was prepared as a guide to assist Corps biologists and natural resource managers in developing moist-soil impoundments that will benefit wildlife using wetland habitats. The use of moist-soil impoundments is especially effective for managing waterfowl habitat in areas of declining wetland acreage. This technique promotes production of naturally occurring wetland vegetation by emulating natural wetland functions. Wetland hydrology is controlled by constructed water delivery, control, and discharge systems; the successional stage of wetland vegetation is manipulated by a combination of soil or vegetative disturbances and appropriate flooding regimes.

This report describes the design and construction of moist-soil impoundments, including desirable site characteristics, levee construction and placement, water-delivery systems, and control structures. The stewardship value of moist-soil impoundments is discussed, and recommendations are given for managing impoundments as single structures or as complexes of smaller units. Strategies are presented for controlling undesirable vegetation and for managing impoundments to accommodate a diversity of wildlife species. Techniques are suggested for monitoring and evaluating moist-soil impoundments at various stages of the annual cycle.

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